

CONTROLLED AMBIENT AERATION DURING RICE STORAGE FOR TEMPERATURE AND INSECT CONTROL

R. P. Ranalli, T. A. Howell Jr., F. H. Arthur, D. R. Gardisser

ABSTRACT. Rice (cv. Cypress) was harvested in September 2000 from a farm near Grady, Arkansas, placed in six, 600-t (31,000-bu) bins [each was filled with ~430 t (21,000 bu)], and dried gently from 18 to 13% moisture content (MC). Three of the bins were aerated by the on-site, storage manager under his normal regimen. Grain temperatures were recorded at four locations within each bin. To monitor insect viability, small cages were filled with approximately 150 g of rice and 20, 1- to 2-week-old mixed sex adults of one insect species. The species that were tested included the lesser grain borer, *Rhyzopertha dominica* (Fauvel); the rice weevil, *Sitophilus oryzae* (L.); and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.). Cages were removed at 5-week intervals, and surviving and emerging insects were counted. Grain temperatures were significantly reduced through controlled aeration relative to the traditional, manual aeration. In addition, both live insect counts and total emerged adult insects recovered from the cages were significantly lower ($p < 0.05$) within the bins treated with controlled aeration. The rice weevils were the hardiest of the insects tested, while saw-toothed grain beetles survived the least. This work indicates that controlled, ambient aeration can be an effective storage treatment against insects and may be a useful alternative to chemical controls.

Keywords. Rice storage, Controlled aeration, Insects.

Rice is a major agricultural product in the United States; especially in Arkansas, California, Louisiana, Texas, Mississippi, and Missouri. The average annual harvest is approximately 90, 30, 25, 15, 15, and 10 million cwt for each state, respectively (Economic Research Service, 1999). From the field to a finished food product, rice undergoes a variety of processes, notably harvesting, drying, storage, and milling.

During the storage period, rice is vulnerable to insect infestation from a variety of stored product insects. There are two main types of insects that infest stored rice, internal feeders, and external feeders. The larvae of internal feeders develop inside the kernel, and the most common ones present in rice are *Rhyzopertha dominica* (Fauvel), the lesser grain borer, and the rice weevil, *Sitophilus oryzae* (L.). The female rice weevil oviposits directly into the kernel, while the female lesser grain borer deposits an egg on the exterior of the kernel, and the first-instar larva bores into the kernel. Upon completion of development, the adult bores through the

kernel and exits, creating a large hole and an insect-damaged kernel. External feeders feed on cracked and broken kernels, in addition to those kernels damaged by internal feeders. Common external feeders present in rice are *Oryzaephilus surinamensis* (L.), the saw-toothed grain beetle, and *Tribolium castaneum* (Herbst), the red flour beetle. Rice quality is directly affected by insect infestation through several different mechanisms: weight losses caused by direct feeding, chemical change as a result of insect feeding and development in the grain, and contamination of the grain with insect body products (Prakash et al., 1987).

The value of rice is predicted on the total weight of rough rice, and the weight of the kernels that remain after the completion of the milling process. Therefore, insect infestation decreases profit because of reduction of dry matter and kernel breakage (Cogburn, 1976). Actual estimates of loss due to infestations from stored grain pests are difficult to quantify but has been estimated from 5 to 15% worldwide (Evans, 1987). However, these loss estimates are conservative because they only take into account actual product destruction and do not consider economic loss due to rejection of rice by grain processors, delays associated with eliminating insect infestations, and economic penalties for infested grains.

Various insecticides have been used to control insect pests in stored rice, but currently only the protectant chlorpyrifos-methyl (Reldan), an organophosphate insecticide, and the fumigant phosphine are used extensively by the rice industry. The organophosphate malathion was used on rice and other stored grains as a protectant, but many stored-product insect species have developed resistance to this chemical (Subramanyam and Hagstrum, 1996). Chlorpyrifos-methyl is the only other insecticide labeled for direct application to stored rice, but recent published reports have stated that lesser grain

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borers are developing resistance to chlorpyrifos-methyl (Zettler and Cuperus, 1990; Arthur, 1992; Guedes et al., 1996).

Currently, the primary chemical used to control insects in bulk-stored rice is the fumigant phosphine, which is an extremely dangerous chemical and can be lethal. Respiratory protection is required when levels exceed 0.3 ppm. Disinfestation of stored grains with phosphine usually requires an exposure period of five days or longer, which makes it unsuitable for quarantine fumigation (Taylor, 1994). Although phosphine will eliminate insect infestations in stored grains, populations often rebound immediately after treatment (Prakash et al., 1987). Phosphine may also be used to fumigate empty metal grain bins (Prakash et al., 1987).

Other possible methods for the protection of stored products from insect infestations would be through the utilization of diatomaceous earth (DE), an inert dust registered to control insects in stored commodities (Quarles, 1992; Quarles and Winn, 1996), or through the utilization of radiation. Although the newer formulations of DE are more effective than the formulations of the past, they can still affect the physical properties of the grain (Korunic et al., 1996). DE could be an effective method for prevention of infestations, but the efficacy of DE is reduced as relative humidity and grain moisture content increase (Korunic, 1997; Arthur, 2000). Radiation could also supply a direct alternative to the fumigation of rice but there are few facilities available for this work.

An important component of integrated pest management programs for stored cereal grains is the use of ambient aeration to cool grain masses to levels that will prevent insect infestation (Noyes et al., 1995; Reed et al., 1993; Reed and Harner 1998a; 1998b). Insects are poikilothermic organisms; therefore, their activity is controlled by their surrounding temperature (Howe, 1965). The optimal temperatures for growth and development have been proposed to be between 25 and 33°C, while 13 to 25°C and 33 to 38°C are considered sub-optimal for most species (Fields, 1992). There have been numerous experiments used to demonstrate the effectiveness of aeration for lowering grain temperatures and controlling insects in corn and wheat storage facilities. Reed and Harner (1998a) compared the use of a three-cycle automatic aeration controller to manual aeration control and to no aeration in field bins and concluded that the cooling of hard winter wheat was most rapid when operated intermittently in three cycles. In a similar study, Armitage and Llewellyn (1987) examined the effectiveness of manually controlled aeration versus automatically controlled aeration (using a thermostat) to control *O. surinamensis* and *S. granarius* in wheat during British winters. The automatically aerated bins were cooled quickest, minimizing the time that the grain was exposed to the optimum temperatures for insect growth (Armitage and Llewellyn, 1987).

Although controlled aeration has been proven as an effective method in corn and wheat, there is little published information on the potential for its use in stored rice, a commodity that is typically stored in warm climates. Hence, the objective of this research was to determine the effectiveness of controlled aeration in lowering grain temperatures in rice and preventing insect infestations relative to traditional, manual aeration.

MATERIALS AND METHODS

RICE STORAGE

Rice (cv. Cypress), harvested in September of 2000 from the Arkansas Department of Corrections Farm located near Grady, Arkansas, was used for the study. The rice was dried from near 18% to between 12 and 14% moisture content (MC) by the farm manager using conventional bin drying methods (dried with air at approximately 32.2°C (90°F) for 2 to 3 days depending on the harvest moisture content of the rice). Three of the bins were used for drying, so after drying, rice was transferred to empty bins for storage. The drying bins were then refilled and used to dry and store the remaining rice that was harvested.

Six bins with a capacity of 630 t each, 12.8 m (42 ft) in diameter and 7 m (23 ft) tall were used for the study. Each bin was filled with approximately 430 t (21,000 bu). Rice in three of the bins was aerated with a thermostatically controlled system, and rice in the three remaining bins was aerated manually, according to traditional practice. The fans [22.4 KW (30 hp), 1750 rpm, GSI, Assumption, Ill.] operated at approximately 1.3 m³/min/t (1.2 cfm/bu), pushing air through the bins. These flow rates are about 10 times larger than flow rates seen in corn and wheat for aeration but are typical for stored rice, as fans are sized for drying in most farm-scale operations.

AERATION SYSTEM

Three test bins were equipped with a thermostatically controlled aeration controller that operated the fans when the ambient air conditions fell below preset conditions (table 1). The controllers were set to cool the rice in three cycles. Initially, the thermostat was set to aerate the rice when the ambient air was 23.9°C (75°F) or below. A humidistat prevented re-wetting of the rice [aeration at high relative humidity (RH)] by preventing fan operation above the preset level. Table 2 shows the effects of temperature and relative humidity on equilibrium moisture content (EMC) of rough rice calculated by the Modified Henderson Equation (*ASAE Standards*, 1997). For this study, the humidistat (in conjunction with the temperature settings) was set so that air with an EMC greater than 14% would not pass through the rice. When the grain temperature equilibrated at or below 23.9°C, the controller was set at 15.5°C (60°F) and 70% RH, and the process was repeated. Finally, the controllers were set at 7.2°C (45°F) and 65% RH. Mathematical simulation studies have shown the potential of using a three-cycle aeration system for stored corn (Arthur et al., 1998; Arthur and Flynn, 2000) and stored wheat (Flinn et al., 1997; Arthur and Flinn, 2000). Rice is significantly more susceptible to damage during storage than these grains, and its value is tied to intact kernels. If the grain were to be rewetted significantly, fissuring could occur, causing major reduction in its value. The control bins were aerated at the discretion of the farm manager, which is the standard practice in the rice industry and varies from manager to manager. Most managers make their decisions based on weather conditions and rice conditions, but lack predictable consistency. In this work, the rice was aerated when the ambient temperature was within 10°C of the rice temperature, and the fans were operated about 3 hours per week.

Table 1. Aeration cycle temperature and relative humidity (RH) settings.^[a]

Cycle	Date	Temperature Setting	RH Setting (%)
1	10/04/00–10/24/00	23.9°C (75.0°F)	75
2	10/24/00–11/28/00	15.5°C (60.0°F)	70
3	11/28/00–01/15/01	7.2°C (45.0°F)	65

^[a] Air conditions must be below bot settings for fans operation.

MONITORING STORAGE TEMPERATURE

Each of the bins was equipped with a HOBO four-channel recorder and thermocouples (Onset Computers, Pocasset, Mass.). The HOBOs were set to record the temperature every 2.5 hours at depths (from the top of the grain) of 0.9 m (3 ft) in north (N), south (S), and center (C) positions and at a depth of 2.7 m (9 ft) in the center of the grain, where cooling is most difficult (Flinn et al., 1997). Temperatures were monitored from the date the rice was placed into the bins, 4 October 2000 until 15 January 2002, the date the rice was removed from the bins. The ambient air temperature and relative humidity were also recorded every 2.5 hours at two locations in close proximity to the fan inlets by HOBO recording sensors.

MONITORING INSECT DEVELOPMENT

All insects used in this study were obtained from pesticide-susceptible colonies maintained at the USDA-ARS-GMPCR, Manhattan Kansas, inside laboratory incubators at constant conditions of 27°C–60% RH. Rice weevils and lesser grain borers were reared on whole-kernel wheat; saw-toothed grain beetles were reared on rolled oats. Approximately 2000 1- to 2-week adults of each species were removed from the colonies, placed in one of three individual jars containing the appropriate rearing media, and shipped overnight to Fayetteville, Arkansas.

PVC couplings [15 cm (6 in.) long with a diameter of 3.81 cm (1.5 in.)] served as cages for live insects. The PVC coupling had fine mesh screens with 0.0185-cm (0.0073-in.) openings (McMaster-Carr Supply Co., Elmhurst, Ill.) placed on each end that allowed for airflow through the cage but did not allow the insects to escape. Once the rice was dried, rice from each bin was taken to fill 18 insect cages with approximately 150 g (0.33 lb) of rough rice.

To each cage, 20 mixed sex adults of the lesser grain borer, the rice weevil, or the saw-toothed grain beetle were added (one species per cage). In each of the six bins in the study, three sets of six cages (with each set consisting of two cages of each of the three different insects) were placed at a depth of 0.5 m (1.5 ft) from the grain surface in the center of the grain mass, where most of the insect activity often occurs

Table 2. Equilibrium Moisture Content (wet-basis) (EMC) of rough rice as a function of temperature and relative humidity, calculated based on the Modified Henderson Equation.^[a]

Temperature (°C)	Relative Humidity (%)			
	45	60	75	90
1.7	12.0	13.9	16.1	19.1
7.2	11.5	13.4	15.5	18.5
15.6	11.0	12.8	14.8	17.7
23.9	10.5	12.3	14.2	17.0
32.2	10.1	11.8	13.7	16.4

^[a] ASAE Standards, 1997.

(Hagstrum, 1987). One set of six cages containing the three insect species in duplicate was removed from each bin at 5-week intervals, starting from the beginning of the study. After the cages are removed from the bins, their contents were analyzed by counting live and dead insects. The rice from each cage was then incubated at approximately 27°C and 57% RH for 5 weeks. After the incubation, live and dead insects were counted to document the total emerging insects from rice kernels.

INSECT TRAPPING

Insect activity within the grain was monitored by placing Storegard WB PROBE II insect traps (TRECE Inc, Salinas, Calif.) in the N, C, and S bin locations. Insect traps were set on 8 January 2001 and removed from the grain on 15 January 2001. The contents of the traps were examined to determine the number and type of insects recovered.

DATA ANALYSIS

Temperature profiles for each of the grain bins were investigated by comparing the temperature profiles of the manually aerated bins to the profiles from the controller-aerated bins. Time of aeration and duration of aeration were investigated to determine their effects on bin temperatures. The statistical analyses of the resulting data were conducted via JMP™ (SAS Institute, Inc., Cary, N.C.). The effects of aeration treatment and sample time on insect counts were evaluated by analysis of variance. Means comparison tests (Duncan's test) were used to determine significant differences for survival rates of the different species as a function of storage duration, and T-tests were used to distinguish the significance of aeration treatments at each storage duration for each specie of insect.

RESULTS AND DISCUSSION

BIN TEMPERATURES

The ambient air conditions along with the controller settings and time of fan operation are displayed in figure 1. The hours of aeration peak when the ambient temperature and ambient RH drop to levels that are optimum for aeration. The figure only shows one temperature and RH value per day (culled from every tenth data point), so the daily cycles of temperature and RH cannot be seen. Consistent with the controller-aerated bins, the on-site farm manager attempted to utilize low temperatures and low relative humidity conditions to aerate the rice. It was a particularly cool autumn and cold early winter, providing farm managers with ideal storage conditions.

An average bin temperature profile for the rough rice stored in the controller-aerated bins is displayed in figure 2. Three distinct cooling cycles are seen that coincide with the three-cycle regimen of the aeration controller. The first cooling cycle took advantage of a cool front in early October. During this cooling cycle the rice was cooled from the high harvest temperature (approximately 25°C) to below 10°C. After this initial cooling cycle, the rice went through a warming trend (to approximately 17°C) dictated by the warm weather conditions. The next cooling cycle coincided with a cool front in late November; cooling the rice another 10°C, to approximately 6 to 10°C. The final cooling cycle took place in late December cooling the rice to below 5°C in all

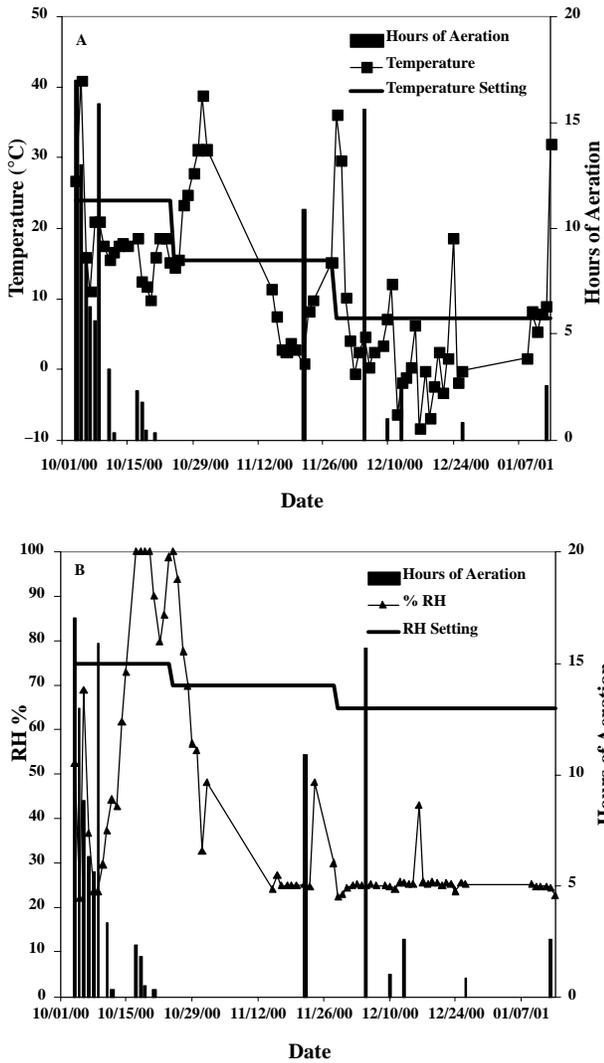


Figure 1. Ambient air temperature (A) and relative humidity (RH) (B) coupled with hours of aeration accumulated by aeration controller as a function of time.

of the bin positions. The center of the bin near the top of the grain mass was the slowest to reach the low temperature, but overall, there were no significant differences in rice temperature based on sampling location in the bin.

The high airflow rates generated quick temperature drops at each cycle. However, in some cases, these quick drops were negated by continued aeration at temperatures above the rice temperature. In the future, closer monitoring of the grain temperature will not only reduce the unnecessary hours of fan operation, but will also allow for the low grain temperatures to remain low. In this set of data (fig. 2), the early significant cooling of the rice was dampened by aeration at higher temperatures (from 10 to 20 October). With closer monitoring, aeration cycle 1 could have been terminated earlier, cycle 2 could have been skipped, and the rice temperature could have been stabilized throughout the season.

In contrast to the controller-aerated bins, the temperature profile for the manually aerated bins (fig. 3) was distinctly different than the temperature profile of the controller-aerated bins. Due to the long harvest duration, the rice was

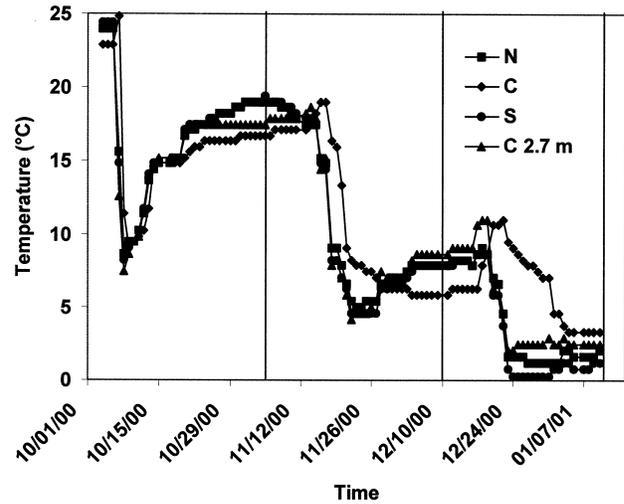


Figure 2. Bin temperature profile for a controller-aerated bin recorded at four bin locations; center (C) (0.9 and 2.7 m), north (N), and south (S) (0.9 m). Vertical bars show insect sampling dates.

placed into the manually aerated bins three days after the rice was placed into the controller-aerated bins. The rice in the manually aerated bins benefited from the cool front in the first week of October (fig. 1), as did the controller-aerated rice. Therefore, the rice in the manually aerated bins began at lower temperatures than the rice in the controller-aerated bins. Although the initial temperatures in the manually aerated bins began at a lower level, they never decreased significantly over the duration of the storage period. In fact, the rice temperatures in the manually aerated bins increased slightly over the duration of the study until late December and early January, when the ambient air temperatures decreased significantly.

EFFECTS OF AERATION TREATMENT ON INSECT VIABILITY

The mean recovered living insects at each sampling time and after rice was incubated are shown in table 3 for each species. In addition, table 3 shows similar data for the total recovered insects (alive and dead) after incubation. The data are useful for understanding how the two aeration treatments affected insect viability during storage. Initial statistical

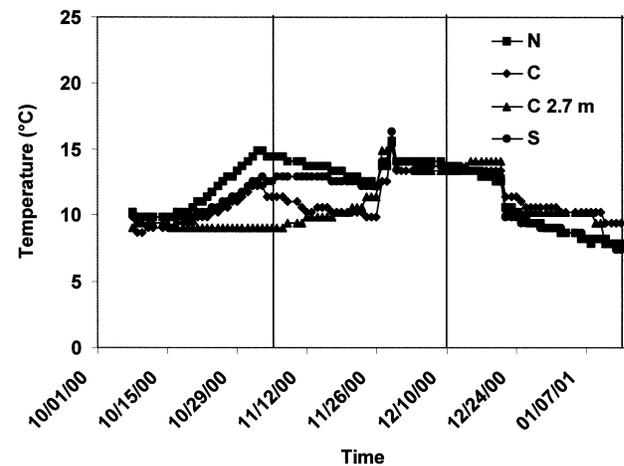


Figure 3. Bin temperature profile for a manually aerated bin recorded at four bin locations; center (C) (0.9 and 2.7 m), north (N), and south (S) (0.9 m). Vertical bars show insect sampling dates.

tests showed that the insect species responded differently to the storage environments. The saw-toothed grain beetle, an external feeder, had no surviving insects at any time, regardless of aeration treatment. These insects feed on broken kernels and debris, and when little is available, they are not able to survive. The lesser grain borer and rice weevil were both able to grow and survive, and their mean recovered living numbers after sampling were not significantly different from each other initially, though there were significantly more rice weevils recovered after incubation (table 3). Also, although some lesser grain borers were found alive at the first two sampling times, they were not effectively reproducing, as shown by their incubation numbers. No insects were recovered from probe traps placed in the bulk rice mass.

Separating the effects of storage duration and aeration treatment on insect survival was complicated by the uncontrollable variables found in field storage work. However, the effects were strong enough to be clearly discovered. Living insects, as discussed previously, respond to reduced temperatures in a predictable manner (reduced activity and fertility below 25°C). Below 13°C, insect activity becomes even further reduced, and reproduction in adults and growth and development of larval instars virtually ceases. The temperature data included in figures 2 and 3 for the two aeration treatments are used to explain not only the effects of duration but also the effects of aeration treatment. If the conditions were suitable for insect activity, live insects would be expected at the sampling time and much insect activity would be expected after incubation at optimum temperatures.

Regardless of whether the analysis of variance was run for the complete data set (all species and both aeration treatments), the individual insect species (at both aeration treatments), or within the individual aeration treatments, storage duration was found to significantly affect insect viability. For either aeration case, the temperatures eventually reached levels well below optimal growth conditions. It was not surprising then to see a corresponding drop in living insects over time. Storage duration in and of itself does not affect insect mortality; however, when it is used to reduce grain temperatures (as in both treatments in this study), it is very effective. This result speaks more to the effectiveness of the aeration treatments than of “duration” itself. If the storage conditions were kept at optimum growth conditions for the insects, a large growth response would have been expected.

While both of the aeration treatments were effective at reducing insect numbers, the controlled aeration strategy was superior to the manual aeration technique. In comparing any of the rows in table 3, the controller-aerated rice bins had fewer living insects or fewer total insects. These numbers were significantly different in every case except at the last sampling period, when the temperature in all of the bins was low enough to have very few survivors. When the temperature profiles are considered (figs. 2 and 3), this result is difficult to explain. The temperatures in the manually aerated bins were relatively low throughout the storage season, suggesting that the insect activity should have been minimized. Upon close examination, however, the temperatures of the rice in the center position hovered just at the lower threshold of sub-optimal growth. In contrast, the rice in the controller-aerated bins showed the distinct cooling cycles that were expected. There were significant times when this rice was at near-optimal conditions for insect activity, but in general, it too was in the sub-optimal range. The major differences between the two aeration schemes was that the controller-aerated bins were able to get to the 5°C range more quickly than the traditionally-aerated bins. At this temperature, insect life would be inhibited greatly. Based on this analysis, insect activity at 5 weeks would be similar for both regimes but would be lower in the controller-aerated bins at 10 and 15 weeks. From table 3, the insects responded in a likewise manner. In addition, the extreme low temperatures of the controller-aerated rice were effective in reducing the egg survival as evidenced by the incubation numbers (living and total) in table 3.

CONCLUSION

This research demonstrated the effectiveness of controlled aeration as a part of an integrated pest management system for the storage of rough rice. Rough rice was cooled rapidly with controlled aeration, thus reducing insect activity within the bins. Insects in bins treated with controlled aeration did not survive as well as those in bins treated under conventional practices. Insect mortality was dependent on species and temperature factors, and both must be considered when storing rice.

Table 3. Mean ± standard error (n = 6) of insects (rice weevil, lesser grain borer, and saw-toothed grain beetle) recovered living at each sampling time, recovered living after incubation, and total recovered (living and dead) after incubation.^[a]

Treatment	Rice Weevil			Lesser Grain Borer			Saw-Toothed Grain Beetle ^[b]		
	5 weeks	10 weeks	15 weeks	5 weeks	10 weeks	15 weeks	5 weeks	10 weeks	15 weeks
Insects alive at sampling									
MA	14 ± 2 ^a	6 ± 3 ^b	0 ± 0 ^c	10 ± 2 ^a	7 ± 2 ^a	1 ± 1 ^b	1 ± 1	0 ± 0	0 ± 0
CA	7 ± 2 ^{a[c]}	0 ± 0 ^b	0 ± 0 ^b	9 ± 1 ^a	1 ± 0 ^{b[d]}	0 ± 0 ^b	0 ± 0	0 ± 0	0 ± 0
Insects alive after incubation									
MA	34 ± 5	23 ± 11	21 ± 10	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
CA	23 ± 5 ^a	0 ± 0 ^{b[d]}	0 ± 0 ^{b[d]}	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Total insects recovered after incubation									
MA	70 ± 8 ^a	31 ± 14 ^b	30 ± 12 ^b	1 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0
CA	31 ± 7 ^{a[c]}	1 ± 0 ^{b[d]}	1 ± 0 ^{b[d]}	0 ± 0	1 ± 0	0 ± 0	0 ± 0	1 ± 0	0 ± 0

^[a] Treatments included manual aeration (MA) and controlled aeration (CA).

^[b] Means of saw-toothed grain beetles were not significantly different for any treatment.

^[c] ^[d] Means of insect counts in manually aerated vs. controller aerated bins were significantly different using a T-test at P < 0.05 or P < 0.10, respectively. Unbracketed letters denote significant differences in means for each aeration treatment and specie as a function of storage duration, as separated by Duncan's test (P < 0.05).

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